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Geographic disparities in mammography uptake among beneficiaries of supplementary health insurance in Minas Gerais, Brazil: an individual-level road-network accessibility study

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Abstract

Purpose

Distance to health services is a recognized dimension of screening inequality, but individual-level evidence from middle-income countries and insured populations is scarce. This study described road-network distance to the nearest and actually used mammography provider and assessed the association between distance to the nearest provider and uptake among beneficiaries of a self-managed health insurance operator in Minas Gerais, Brazil.

Methods

Cross-sectional study of 14,474 women aged 40–74 years enrolled in 2024. Road-network distance and car travel time to the nearest of 188 accredited providers and distance to the provider actually used were estimated with the Open Source Routing Machine. The outcome was mammography in 2023–2024. Logistic regression estimated odds ratios (ORs) by distance quartile, adjusted for age, primary health care (PHC) enrollment and capital versus noncapital residence. Travel-time bands, a municipality random intercept and the IBGE rural–urban typology were also examined.

Results

The overall uptake was 64.5%. Three quarters lived within 7.5 km of a provider, yet 407 of 494 municipalities had none. Uptake was similar across the three nearest quartiles (65.9–67.6%) and fell to 57.0% in the farthest quartile (adjusted OR 0.75, 95% CI 0.68–0.82). Uptake was lower in intermediate (53.3%) and rural (57.8%) than in urban municipalities (65.5%), but not significantly in the multilevel model (p = 0.08). PHC enrollment was associated with higher uptake (OR 2.06, 1.90–2.23).

Conclusion

Even with the examination covered, lower uptake was concentrated among women farthest from the network in underserved regions. PHC-led outreach targeted at these territories may help reduce geographic disparities in screening.

Introduction

Breast cancer is the most frequently diagnosed cancer and the leading cause of cancer death among women, both worldwide [1] and in Brazil [2]. In Brazil, excluding nonmelanoma skin cancer, approximately 74,000 new cases per year were estimated for 2023–2025 [2]. Mammography screening reduces breast cancer mortality [3], but its impact depends on women being able to reach the services that perform the examination.

Access to health care has several dimensions, such as availability, affordability and acceptability [4]. One of them is geographic accessibility, expressed as the distance and travel time between residence and service. Longer distances have been associated with lower use of cancer services and with later stage at diagnosis [5, 6].

Studies from different countries show that distance is also associated with screening. In the United Kingdom, participation in mammography screening decreased as distance to the service increased [7]; in the United States, limited geographic access to mammography is concentrated among rural and older women and accompanies lower screening uptake [8–10].

Because geographic remoteness often overlaps with socioeconomic disadvantage, geography is recognized as an axis of inequality along the breast cancer care continuum [11].

In Brazil, mammography equipment is unevenly distributed across regions, and many women must travel long distances to be screened [12]. The proportion of women who had ever had a mammogram was lower among those living in municipalities far from the equipment [13], and installing mammography units in municipalities that previously had none increased the number of examinations performed [14].

The Brazilian health system comprises the Unified Health System (SUS), which is public and universal, and the supplementary health sector, made up of private and self-managed health insurance operators. Breast cancer screening is largely opportunistic, and mammography coverage is lower among women who depend exclusively on the SUS than among those covered by supplementary health insurance [15, 16].

Brazilian studies on this topic, however, have relied on aggregated data and focused on the public system, in which organisational barriers, such as difficulties with scheduling and follow-up, add to geographic barriers [12, 17, 18]. Little is known about what happens when the financial barrier is reduced: among beneficiaries of supplementary health insurance, is distance still associated with mammography uptake? And if so, in which territories?

Minas Gerais has the largest number of municipalities of any Brazilian state, 853 [19], a large territory and important regional inequalities: specialized services are concentrated in the capital and in regional hubs, whereas the northern and northeastern regions of the state, which have the lowest human development indices, have service gaps [20–22].

This study described road-network distances to the nearest and actually used mammography provider and assessed the association between distance to the nearest provider and mammography uptake among beneficiaries of a nonprofit, self-managed health insurance operator organized around primary health care (PHC) in Minas Gerais.

It was hypothesized that longer distances would be associated with lower mammography uptake, independent of age, PHC enrollment and place of residence.

Methods

Study design and setting

This was an observational, analytical, cross-sectional study with a spatial approach, reported according to the STROBE statement [23]. It was conducted in Minas Gerais, a state in southeastern Brazil with approximately 20.5 million inhabitants living in 853 municipalities [19].

The operator analyzed is a nonprofit, self-managed health insurance operator that provides care through its own and an accredited provider network, with care coordination led by PHC teams.

Participants and providers

All female beneficiaries aged 40–74 years with active enrollment in 2024 and residence in Minas Gerais were included (n = 14,474). This age range corresponds to the population of interest defined by the operator's institutional screening protocol, which recommends routine screening from 45 years of age and from 40 years according to individual risk.

Eligibility, residence, PHC enrollment and the provider network were defined for 2024; enrollment history in 2023 was not considered. One woman with a recorded age of 80 years, probably a registration error, was retained in the analyses.

In 2025, the Brazilian Ministry of Health began recommending biennial mammography screening for women aged 50–74 years and allowing on-demand examination at 40–49 years after counseling on its risks and benefits [24].

Eligible providers were the 188 accredited facilities active in December 2024 with at least one paid claim for the following codes of the Brazilian supplementary health terminology (TUSS): 40808033 (bilateral conventional mammography), 40808041 (bilateral digital mammography), 41001320 (digital breast tomosynthesis) and 40808173 (xeromammography).

Data sources and geocoding

Mammography claims for 2023–2024 and enrollment data were extracted from the operator's information systems. Women's residential locations were derived from the postal code (CEP) recorded at enrollment and provider addresses from the accredited network register.

Geocoding was performed in R in three steps: (1) postal-code geocoding using the CEP Aberto collaborative database; (2) complementary geocoding with OpenStreetMap and ArcGIS Online through the tidygeocoder package [25]; and (3) linkage to the National Address Register for Statistical Purposes (CNEFE) of the 2022 Census [26].

For each address, the most precise coordinate available was retained in the following order: full CNEFE address, CNEFE address without house number, OpenStreetMap/ArcGIS result and postal-code centroid from CEP Aberto.

Distance and travel-time measures

Road-network distances (km) between each woman's residence and every eligible provider were estimated with the Open Source Routing Machine (OSRM) [27], assuming car travel under free-flow traffic conditions. The minimum distance was defined as the distance to the nearest accredited provider and was categorized into quartiles of the study population (Q1 to Q4).

Travel-time isochrones of 15, 30, 45 and 60 min were generated for each provider and merged into a single network layer so that each location was assigned the shortest travel-time band to any provider. For women who underwent mammography, the distance to the provider actually used was also estimated; when a provider had more than one address, the address nearest to the residence was used.

Outcome and covariates

The outcome was any mammography in 2023–2024 (yes/no). Covariates were age (continuous, years), PHC enrollment in 2024 (registration with one of the operator's PHC teams during the year; yes/no) and municipality of residence, classified as capital (Belo Horizonte) or noncapital. This classification is operational and does not, by itself, measure socioeconomic vulnerability.

Municipalities were also classified according to the rural–urban typology of the Brazilian Institute of Geography and Statistics (IBGE), which considers the population living in densely occupied areas, its share of the municipal population and the proximity to larger urban centers [28]; its five classes were grouped as urban, intermediate (adjacent or remote) and rural (adjacent or remote).

Statistical analysis

Absolute and relative frequencies described mammography uptake by age group, PHC enrollment, place of residence and distance quartile. Distance indicators (mean, median, 95th percentile [P95], minimum, maximum and standard deviation) were calculated for the state and for each municipality.

The odds of mammography uptake by quartile of minimum distance (reference: Q1) were estimated with logistic regression in a crude model and in a model adjusted for age (linear term), PHC enrollment and place of residence. Goodness of fit was assessed with the likelihood ratio and Hosmer–Lemeshow tests.

Two sensitivity analyses were performed: (i) replacing distance quartiles with travel-time bands to the nearest provider; and (ii) a mixed-effects logistic model with a random intercept for municipality of

residence in place of the capital/noncapital variable. Between-municipality variation was expressed as the intraclass correlation coefficient (ICC) using the latent-variable approach.

Rural–urban differences were assessed with municipality-aggregated counts using the χ^2 test and mixed-effects logistic models with a random intercept for municipality fitted without and with the municipal mean minimum distance (per 10 km). Because these models include only municipal-level covariates, they are equivalent to individual-level models with the same covariates but do not allow adjustment for individual characteristics.

As secondary analyses, quantile regression [29], crude and adjusted for age, PHC enrollment and place of residence, was used to describe how minimum distance differed between women who did and did not undergo mammography at the 25th, 50th and 75th percentiles, and Spearman's correlation was used to examine municipality-level associations between distance indicators and mammography coverage (Online Resource 1). Two-sided tests with a 5% significance level were used. Analyses were performed in R version 4.4.3 [30].

During manuscript preparation, a large language model (Claude, Anthropic) was used to assist with translation into English. All content was reviewed and edited by the authors, who take full responsibility for the manuscript.

Results

Study population and mammography uptake

Of the 14,474 eligible women, 9,333 (64.5%) underwent at least one mammography in 2023–2024; uptake was 67.8% among women aged 50–69 years and 65.9% among those aged 50–74 years. Uptake was highest at 55–64 years (69.1–69.4%) and lowest at 40–44 years (55.9%) and 70–74 years (59.2%) (Table 1).

Overall, 31.5% of women were enrolled in PHC; uptake was 76.0% among enrolled and 59.2% among nonenrolled women.

Table 1
Characteristics of women aged 40–74 years and mammography uptake in 2023–2024, Minas Gerais, Brazil (n = 14,474)

Characteristic	n (%)	Mammography uptake, %
Total	14,474 (100.0)	64.5
Age group, years[a]		
40–44	2,281 (15.8)	55.9
45–49	1,979 (13.7)	67.1
50–54	1,677 (11.6)	67.6
55–59	1,807 (12.5)	69.1
60–64	2,235 (15.4)	69.4
65–69	2,293 (15.8)	65.2
70–74	2,201 (15.2)	59.2
PHC enrollment[b]		
Yes	4,560 (31.5)	76.0
No	9,914 (68.5)	59.2
Place of residence		
Capital (Belo Horizonte)	4,028 (27.8)	70.1
Noncapital municipality	10,446 (72.2)	62.3
Minimum distance to nearest provider (quartile)		
Q1 (0.00–1.31 km)	3,619 (25.0)	67.4
Q2 (1.31–2.61 km)	3,619 (25.0)	65.9
Q3 (2.61–7.50 km)	3,618 (25.0)	67.6
Q4 (7.50–264.52 km)	3,618 (25.0)	57.0

PHC, primary health care. [a] Age groups sum to 14,473; the total includes one woman with a recorded age of 80 years, outside the eligibility range. [b] Registration with a PHC team of the operator in 2024

Geographic distribution of women and providers

The capital concentrated 27.8% of eligible women, followed by Juiz de Fora (6.4%), Uberlândia (5.5%) and Montes Claros (3.6%). Of the 188 providers, 46 (24.5%) were located in four municipalities (Belo

Horizonte, Uberlândia, Juiz de Fora and Governador Valadares), and 407 (82.4%) of the 494 municipalities with eligible beneficiaries had no accredited provider within their boundaries (Fig. 1).

Three quarters of women lived within 7.5 km of the nearest provider. Distances were homogeneous from Q1 to Q3 (SD ≤ 1.28 km) and more dispersed in Q4 (median 33.4 km; maximum 264.5 km), and 6.0% of women lived more than 60 km from any provider (Table 2).

Municipal medians of minimum distance ranged from 0.8 to 241.1 km; 118 municipalities (23.9%) had a median above 60 km, located predominantly in the North and Northwest of the state, in the Jequitinhonha and Mucuri valleys and in parts of the Triângulo Mineiro (Fig. 2; Online Resource 2).

By car, 78.7% of women were within 15 min of the nearest provider, 4.8% within 15–30 min, 5.1% within 30–45 min and 3.9% within 45–60 min, whereas 7.5% were not reached by any isochrone of up to 60 min (Fig. 3).

Table 2
Road-network distance (km) from residence to the nearest accredited mammography provider and to the provider actually used, Minas Gerais, Brazil

Group	n	Uptake, %	Mean	Median	P95	Min	Max	SD
Distance to nearest provider, by quartile								
Q1 (shortest)	3,619	67.4	0.82	0.85	1.27	0.00	1.31	0.31
Q2	3,619	65.9	1.90	1.87	2.53	1.31	2.61	0.38
Q3	3,618	67.6	4.26	3.94	6.86	2.61	7.50	1.28
Q4 (longest)	3,618	57.0	47.62	33.39	147.82	7.50	264.52	42.41
Distance to provider actually used[a]								
Screened women with valid route	7,008	–	35.90	4.44	199.24	0.02	1,121.50	87.91

P95, 95th percentile; SD, standard deviation. [a] Women who underwent mammography in 2023–2024 and for whom a valid route to the provider used could be estimated (7,008 of 9,333; 75.1%). The unit is the examination: women with more than one mammography contribute one trip per examination

Distance to the provider actually used could be estimated for 7,008 of the 9,333 screened women (75.1%); the remaining 2,325 (24.9%) were lost in provider linkage, geocoding or routing. Across the examinations of these women, the median distance traveled was 4.4 km, but the mean was 35.9 km and the P95 199.2 km (Table 2).

In the total population, the mean distance to the nearest provider was 13.6 km. Of approximately 13,600 mammograms performed in 2023–2024, 72.6% were concentrated in 43 provider addresses located in

22 municipalities.

Association between distance and mammography uptake

In the crude model, only Q4 differed from Q1 (OR 0.64, 95% CI 0.58–0.71). After adjustment, the association in Q4 was attenuated but remained significant (OR 0.75, 95% CI 0.68–0.82; p < 0.001): women farthest from the network had approximately 25% lower odds of undergoing mammography than those living nearest to it, whereas Q2 and Q3 did not differ from the reference (Table 3).

PHC enrollment was the factor most strongly associated with uptake (OR 2.06, 95% CI 1.90–2.23), and noncapital residence was independently associated with lower odds (OR 0.85, 95% CI 0.78–0.92). The adjusted model fit better than the crude model (likelihood-ratio test p < 0.001), although the Hosmer–Lemeshow test suggested imperfect calibration (p < 0.001).

Table 3
Odds ratios for mammography uptake in 2023–2024 according to minimum road-network distance to the nearest accredited provider, Minas Gerais, Brazil (n = 14,474)

Variable	Crude OR (95% CI)	Adjusted OR (95% CI)[a]	Multilevel OR (95% CI)[b]
Minimum distance quartile			
Q1 (≤ 1.31 km)	1 (ref.)	1 (ref.)	1 (ref.)
Q2 (1.31–2.61 km)	0.94 (0.85–1.03)	0.92 (0.83–1.01)	0.92 (0.83–1.01)
Q3 (2.61–7.50 km)	1.01 (0.92–1.12)	0.95 (0.86–1.05)	0.94 (0.84–1.04)
Q4 (7.50–264.52 km)	0.64 (0.58–0.71)***	0.75 (0.68–0.82)***	0.79 (0.70–0.90)***
Covariates			
Age (per year)	–	1.00 (1.00–1.01)*	1.00 (1.00–1.01)**
PHC enrollment (yes vs no)	–	2.06 (1.90–2.23)***	1.95 (1.79–2.13)***
Noncapital vs capital residence	–	0.85 (0.78–0.92)***	–

CI, confidence interval; OR, odds ratio; PHC, primary health care. [a] Logistic regression adjusted for all variables shown. [b] Mixed-effects logistic regression with a random intercept for municipality of residence (494 municipalities), replacing the capital/noncapital variable; between-municipality variance 0.169; intraclass correlation coefficient 4.9%. *p < 0.05; **p < 0.01; ***p < 0.001

The results were consistent in sensitivity analyses. Compared with women within 15 min of a provider, those beyond 60 min or outside any isochrone had lower odds of uptake (OR 0.65, 95% CI 0.57–0.74), as

did those at 30–45 min (OR 0.81, 95% CI 0.69–0.94), with no significant difference at 15–30 or 45–60 min (Online Resource 1).

In the multilevel model, the association in Q4 persisted (OR 0.79, 95% CI 0.70–0.90), and 4.9% of the residual variance in uptake was attributable to the municipality of residence (Table 3).

In secondary analyses, screened women lived closer to providers at all percentiles of the distance distribution, and the gap widened in the upper tail (adjusted difference − 0.12 km at the 25th, − 0.31 km at the 50th and − 1.93 km at the 75th percentile). The excess distance associated with noncapital residence rose from 0.30 km at the median to 12.19 km at the 75th percentile.

At the municipal level, all distance indicators were weakly and inversely correlated with mammography coverage (ρ between − 0.188 and − 0.118; $p \leq 0.009$) (Online Resource 1).

Rural–urban disparities

Of the 494 municipalities with eligible women, 180 were classified as urban, 81 as intermediate and 233 as rural; urban municipalities contained 89.4% of the women. Uptake was 65.5% in urban, 53.3% in intermediate and 57.8% in rural municipalities (χ^2 test, $p < 0.001$), and the mean distance to the nearest provider was 8.2, 65.6 and 54.1 km, respectively (Table 4; Online Resource 2).

In the multilevel model, the global test for typology was not significant (likelihood-ratio test $p = 0.08$). In exploratory contrasts, women living in intermediate municipalities had lower odds of uptake than those in urban municipalities (OR 0.78, 95% CI 0.62–0.97), whereas the difference for rural municipalities was not significant (OR 0.94, 95% CI 0.78–1.14).

After adjustment for the municipal mean distance to the nearest provider, both estimates approached the null (OR 0.96 and 1.10), while each additional 10 km was associated with 5% lower odds of uptake (OR 0.95, 95% CI 0.93–0.97).

Table 4
Mammography uptake in 2023–2024 and distance to the nearest accredited provider according to the IBGE rural–urban typology of the municipality of residence, Minas Gerais, Brazil (n = 14,474)

Rural–urban typology	No. of municipalities	Women, n (%)	Uptake, %	Distance to nearest provider, km[a]	OR (95% CI)[b]	Adjusted OR (95% CI)[c]
Urban	180	12,943 (89.4)	65.5	8.2	1 (ref.)	1 (ref.)
Intermediate	81	711 (4.9)	53.3	65.6	0.78 (0.62–0.97)*	0.96 (0.76–1.21)
Adjacent	79	699 (4.8)	53.5	64.6	–	–
Remote	2	12 (0.1)	41.7	124.8	–	–
Rural	233	820 (5.7)	57.8	54.1	0.94 (0.78–1.14)	1.10 (0.91–1.34)
Adjacent	226	802 (5.5)	57.7	52.8	–	–
Remote	7	18 (0.1)	61.1	111.4	–	–

CI, confidence interval; OR, odds ratio. Uptake differed across urban, intermediate and rural municipalities (χ^2 test, $p < 0.001$). [a] Mean minimum road-network distance, weighted by the number of women. [b] Mixed-effects logistic regression with a random intercept for municipality (494 municipalities) fitted to municipality-aggregated counts; intraclass correlation coefficient 6.0%; likelihood-ratio test for typology p = 0.08. [c] Additionally, adjusted for the municipal mean minimum distance (OR 0.95 per 10 km, 95% CI 0.93–0.97); intraclass correlation coefficient 5.0%. Excluding Belo Horizonte, the ORs for intermediate and rural municipalities were 0.78 (0.63–0.97) and 0.95 (0.79–1.15), respectively. *p < 0.05

Discussion

Two findings stand out among the beneficiaries of the operator studied. First, the association between distance and mammography uptake was not gradual: there was no significant difference among the three nearest quartiles, which comprised women living within 7.5 km of the nearest provider, whereas in the farthest quartile, the odds of screening were approximately 25% lower after adjustment.

This association persisted when distance was replaced by travel time and when municipality of residence was taken into account. Coverage of the examination by the operator therefore did not remove the association with distance among women living farthest from the network.

The second finding is the association with PHC. Women enrolled in PHC had approximately twice the odds of undergoing mammography (OR 2.06), the largest magnitude among the variables analyzed, and this association persisted in the multilevel model (OR 1.95). Distance and PHC enrollment were

independently associated with uptake, which suggests that beyond the location of services, the organization of care is also related to screening.

A possible explanation, described in the literature, is the role of PHC in coordinating preventive care through active recommendation, reminders and scheduling support [17, 18].

At the territorial level, the longest distances were concentrated in the North and Northwest of Minas Gerais and in the Jequitinhonha and Mucuri valleys, the regions with the lowest human development indices in the state [22]. Noncapital residence was associated with lower uptake even after adjustment for distance and PHC enrollment.

The IBGE rural–urban typology pointed in the same direction, although with weaker evidence. Crude uptake in intermediate and rural municipalities was 8 to 12 percentage points lower than in urban municipalities, but the global test in the multilevel model was not significant, and the estimates approached the null after adjustment for the municipal mean distance.

These municipality-level analyses do not allow mediation by distance to be assessed; they are only compatible with the hypothesis that distance contributes to lower uptake outside urban centers.

These findings are in line with international evidence that geographic remoteness and socioeconomic disadvantage overlap along the breast cancer care continuum [6, 11] and that limited access to mammography is concentrated in rural areas [9, 10]. They are also in line with Brazilian studies that observed lower uptake among women living in municipalities far from mammography equipment [12, 13].

In the quantile regression, the excess distance associated with noncapital residence was small in the lower percentiles and reached approximately 12 km at the 75th percentile. Average-based indicators, which suggest good accessibility for most women, may not reveal this difference.

The absence of a gradient across the three nearest quartiles may reflect, as a hypothesis, a threshold beyond which distance becomes a barrier rather than a continuous effect; studies on geographic access to mammography commonly use travel-time cut-offs to identify women with limited access [9, 10].

In addition, because three quarters of women lived within 7.5 km of a provider, the contrast in distance among these quartiles was small (means of 0.8 to 4.3 km), which limits the ability to detect differences between them.

The network was only partially compatible with the Brazilian Ministry of Health planning parameter, which sets a maximum travel of 60 km or 60 min for access to mammography [31]. Although 78.7% of women were within 15 min of a provider, 6.0% lived more than 60 km away, and 7.5% were outside the 60-min isochrones.

Overall uptake (64.5%) was higher than estimates for opportunistic screening in the SUS in Minas Gerais (44.5%) [16] but lower than the self-reported coverage among Brazilian women covered by supplementary health insurance in the 2013 National Health Survey (79.5%) [15].

A direct comparison, however, is not possible. The studies differ in data source (claims versus self-reports), age ranges and observation windows, and the national estimate pools beneficiaries of a large number of operators with different networks, care models and beneficiary profiles.

Nevertheless, approximately one-third of the target population was not screened in the biennium, even though the examination was covered by the operator. This suggests the presence of other barriers, such as those described in the Brazilian literature [17, 18], which were not assessed in this study.

Lower uptake at 40–44 years should be interpreted in light of the institutional protocol and the 2025 national recommendation, which allow screening at these ages according to individual risk or on demand [24].

Proximity to a provider did not necessarily mean its use. The median distance to the provider actually used was 4.4 km, but the mean was 35.9 km, higher than the mean distance to the nearest provider in the study population (13.6 km), and use was concentrated in 43 provider addresses.

In the United States, only approximately one-third of women used the closest mammography facility, but most of those who bypassed it used a facility within 5 min of the nearest one [32].

Perceived quality, appointment availability, proximity to the workplace and referral flows are plausible hypotheses for these choices, but they were not measured in this study. Part of these trips may also reflect the search for regional hubs with broader supply.

These results suggest implications for planning. The organization of the accredited network could consider, beyond the number of providers, geographic proximity, service capacity and observed patterns of use.

For women in the farthest quartile, strategies such as active outreach by PHC teams, coordinated scheduling, transport support and mobile mammography units could be evaluated in the municipalities identified in this study. Lower uptake at 70–74 years also deserves attention, as mobility limitations may add to distance [8].

Strengths and limitations

The strengths of this study include the individual-level design covering the entire eligible population of the operator in the state; geocoding with multiple national and open data sources; the use of road-network distances and travel times rather than straight-line distances; the integration of potential and realized access; and the consistency of results across different specifications.

Some limitations should be considered. First, residence was assumed to be the origin of the trip, and distances were estimated for car travel under free-flow traffic, which may underestimate the burden for women who rely on public transport or travel from their workplace.

Second, the outcome was based on claims, which do not distinguish screening from diagnostic mammography and do not capture examinations performed outside the operator, for example, in the SUS or paid out of pocket; uptake may therefore have been under- or overestimated.

Third, eligibility and covariates were defined for 2024, whereas the outcome covered 2023–2024, so changes in enrollment, address or network were not captured. Fourth, the distance to the provider actually used could not be estimated for 24.9% of screened women.

Fifth, age was modeled as a linear term, although crude uptake varied nonmonotonically across age groups, and the Hosmer–Lemeshow test suggested imperfect calibration, which warrants caution. Sixth, the rural–urban analysis relied on municipality-aggregated data and could not be adjusted for individual characteristics.

Finally, given the cross-sectional design, the associations observed do not allow causal inference; in particular, PHC enrollment (2024) and mammography uptake (2023–2024) were observed over the same period. In addition, beneficiaries of the operator may differ socioeconomically from the general population, which limits generalisability to women who depend exclusively on the SUS.

Conclusion

In Minas Gerais, the accredited network provided geographic proximity for most beneficiaries of the operator, but distance remained associated with lower mammography uptake among women living farthest from the network, who were concentrated in the interior and in the most underserved regions of the state. Coverage of the examination was not sufficient to ensure similar uptake across the territory.

Network planning based on geographic accessibility, combined with PHC-led active outreach in these territories, may help reduce geographic disparities in early detection.

Declarations

Competing interests

None

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki and Resolutions No. 466/2012 and No. 510/2016 of the Brazilian National Health Council. Approval was granted by the Research Ethics Committee of Centro Universitário de Brasília (CEP-UniCEUB), designated through Plataforma Brasil, the national research ethics review system (Opinion No. 8,597,911, 3 July 2026; CAAE 97838226.7.0000.0023).

Clinical trial number

not applicable.

Consent to participate

The requirement for informed consent was waived by the Research Ethics Committee because the study used pseudonymised administrative data.

Consent to publish

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Author Contribution

N.O.H. and A.C.M.G.F. conceived the study. N.O.H., C.H.O.C. and A.C.M.G.F. developed the methodology. N.O.H. and D.M.C. performed the formal analysis. N.O.H. carried out the investigation and prepared the figures. N.O.H. and C.H.O.C. curated the data. D.F.O. validated the results, administered the project and supervised the work. N.O.H. wrote the original draft. All authors reviewed and edited the manuscript, approved the final version and agree to be accountable for all aspects of the work.

Data Availability

The individual-level data analysed in this study were obtained from the administrative databases of the health insurance operator and are not publicly available because they contain personal health information protected by the Brazilian General Data Protection Law (Law No. 13,709/2018). The data are, however, available from the corresponding author upon reasonable request and with the permission of

the operator. Aggregated municipality-level data supporting the findings of this study are provided in Online Resource 2, with values suppressed for municipalities with fewer than 10 eligible women to protect confidentiality.

Abbreviations

CI, confidence interval; ICC, intraclass correlation coefficient; OR, odds ratio; OSRM, Open Source Routing Machine; P95, 95th percentile; PHC, primary health care; SD, standard deviation; SUS, Unified Health System (Sistema Único de Saúde)

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Figures

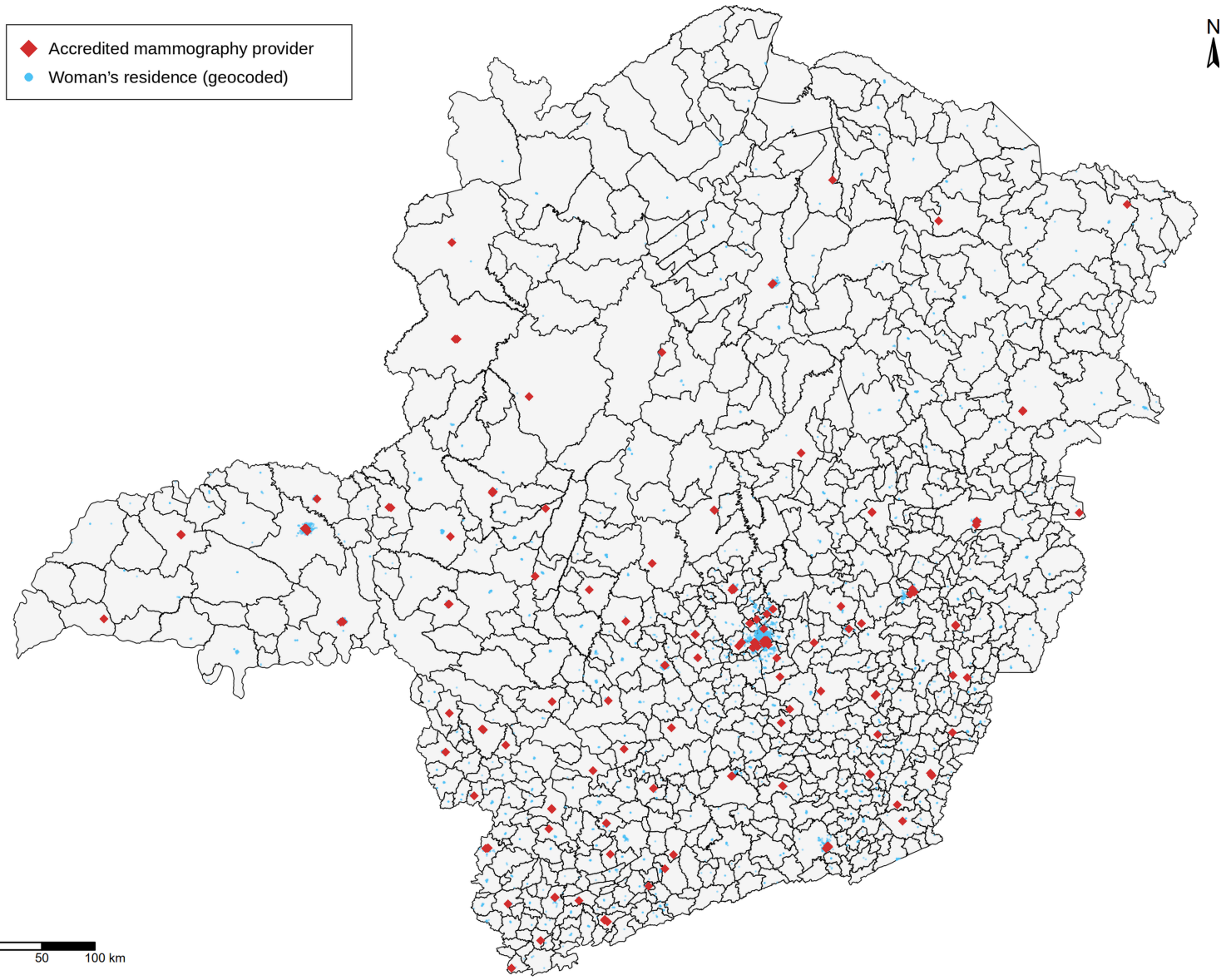

Figure 1

Residential locations of women aged 40–74 years (dots) and accredited mammography providers (diamonds), Minas Gerais, Brazil, 2024

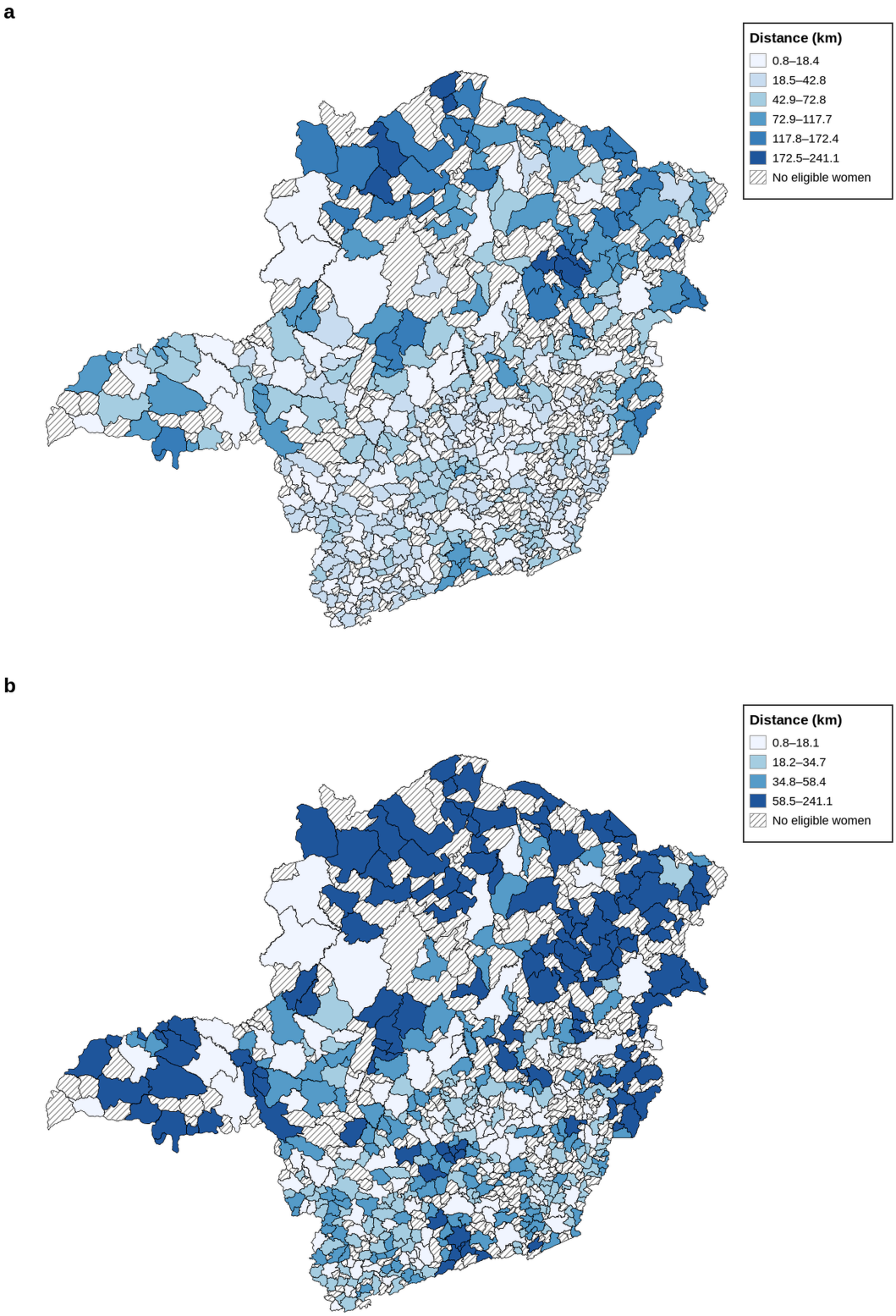

Figure 2

Median road-network distance (km) from residence to the nearest accredited mammography provider, by municipality of residence, Minas Gerais, Brazil, 2024. **a** Jenks natural breaks; **b** quartiles. Hatched areas indicate municipalities without eligible women.

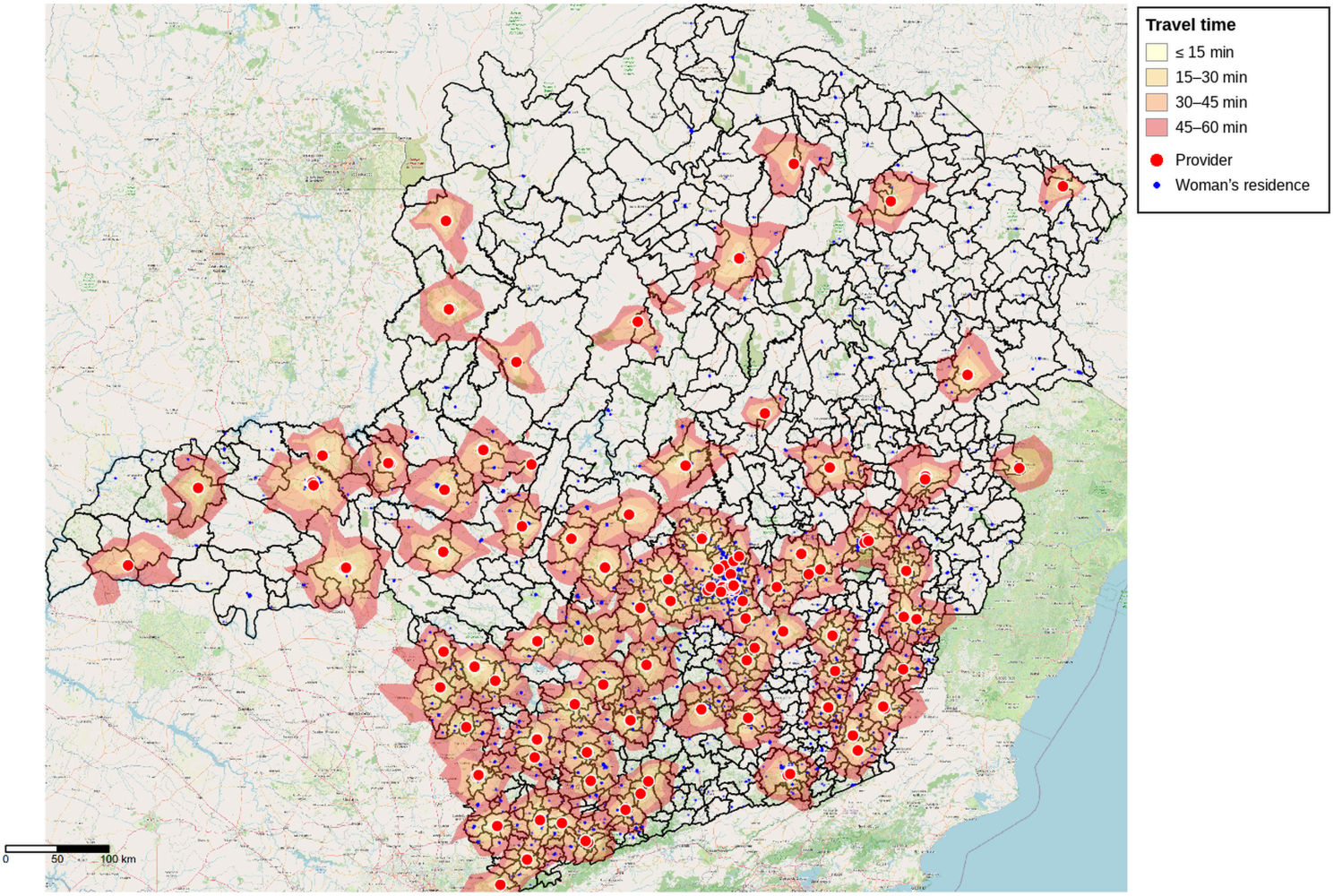

Figure 3

Car travel-time isochrones (15, 30, 45 and 60 min) to the nearest accredited mammography provider, Minas Gerais, Brazil, 2024. Large red dots indicate providers; small blue dots indicate women's residential locations. Base map © OpenStreetMap contributors

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